Soil surface compaction: How land abandonment interacts with fire in Mediterranean conditions

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1. Abstract

The abandonment of agricultural landscapes has been a widespread phenomenon in European Mediterranean areas since the second half of the past century. Land abandonment promotes soil structuration and increases soil organic matter content, even though the abandoned land is still affected by old degradation processes from cropping. In addition, old fields are often colonised by opportunistic plant species, giving way to fire-prone formations.

This work presents an nine-year monitoring of soil surface compaction which includes unburned and burned areas and two stages of abandonment: (1) lands abandoned 8-15 years prior to fire and occupied by dry grassland with young *Pinus halepensis*, and (2) old fields (>35 years of abandonment) colonised by mature pine forest. The study area is located near the Guadalest reservoir (Alacant province, E Spain). Soil surface compaction (0-1 cm mineral soil depth) was assessed by means of a cone penetrometer.

Analysis of unburned areas showed that the pine forest always presented lower values of soil surface compaction than the more recently abandoned fields. After burning, both stages of abandonment showed increased compaction during the first year, although their subsequent dynamics in this respect were quite different. In the recently abandoned fields, soil surface compaction values returned to those found on unburned plots in the short term. In contrast, burned pine forest showed higher values than unburned pine forest until the sixth year after the fire.

These results indicate that old fields colonised by pine forest are more vulnerable to fire than recently abandoned fields in terms of soil compaction.

2. Introduction

The abandonment of marginal agricultural landscapes has been a widespread phenomenon in European Mediterranean areas since the second half of the past century (Margaris et al., 1996; Puigdefábregas and Mendizábal, 1998). Even though some of the soil traits generated by the previous human activities persist, land abandonment promotes successive changes in soil organic matter, structural stability and other physico-chemical characteristics (Martínez-Fernández et al., 1995; Kosmas et al., 2000; Dunjó et al., 2003). Likewise, agricultural land abandonment promotes deep changes in the composition and spatial arrangement of the plant communities (Barbero et al., 1990), increasing both the fuel load and the risk of severe wildfires (Pérez et al., 2003; Vallejo et al., 2005).

Forest fires cause impacts on physical, chemical and microbiological soil processes and dramatically reduce plant cover (Neary et al., 1999; Certini, 2005), leaving the soil surface unprotected. The impact of raindrops on an unprotected soil surface promotes aggregate disruption by splash, soil sealing and crusting. Soil surface sealing and crusting disturb the gas and heat flow between the soil and the atmosphere, make seedling emergence difficult, and reduce water infiltration (Marshall and Holmes, 1988; Ramos et al., 2000).

In this work, we hypothesise that the age of land abandonment is a key factor in determining the soil response to fire in terms of soil surface compaction.

3. Methods

The study area is located on the south-facing slopes of the Xortà range, which drain into the Guadalest reservoir (Alacant province, E Spain). Coordinates are 38º41'N, 0º12'W and altitude ranges between 400 m and 500 m. The climate is dry mesomediterranean, with mean annual precipitation of 475 mm and mean annual temperature of 15.6 ºC. Soil parent materials are Miocene marls with some limestone (IGME, 1975). The dominant soil type is *Calcaric Cambisol* (FAO, 2001), poor in organic matter and loamy in texture. The slopes are structured into agricultural terraces, most of which are abandoned. Land is divided among many small property owners, resulting in a mosaic of intermixed conditions of abandonment, from crops in use to mature *Pinus halepensis* forests that colonised old fields.

This site was partially affected by a wildfire in August 1998, and the area burned was irregular in shape. The result was a scattered mosaic of land uses, both burned and unburned.

We selected 12 abandoned agricultural terraces (6 burned and 6 unburned) corresponding to two ages of abandonment: (1) recently abandoned fields (abandoned between 8 and 15 years before the fire and occupied by dry grassland dominated by *Brachypodium retusum* with young *P. halepensis* and some remaining *Olea europaea*, *Ceratonia siliqua* and *Prunus dulcis*) and (2) pine forest (old fields abandoned more than 35 years prior to the fire and spontaneously colonised by mature *P. halepensis* forest with a dense undergrowth dominated by shrubs, i.e., *Ulex parviflorus* and *Rosmarinus officinalis*).

Soil surface compaction (0-1 cm mineral soil depth) was measured using a cone penetrometer for the top layers (Eijkelkamp Agrisearch Equipment, model 02.02). Sampling points (5 per terrace) were distributed along linear transects. We took ten measurements at each sampling point and used the mean values for the data analysis. The first series of measurements was carried out three months after the fire, and this was followed by samplings at 12, 24, 48, 59, 71 83, 96 and 108 months after the fire. Measurements were always made during dry periods. Data were analysed using the repeated measures analysis test, with Age of abandonment and Fire as the between-subject factors and Time as the within-subject factor.

4. Results and discussion

The topsoil in the unburned pine forest showed the lowest penetration resistance values (Figure 1). Annual values ranged between 3100 kPa and 1600 kPa, and the mean throughout the whole study period was 2370 kPa. In contrast, the burned pine forest showed the highest topsoil penetration resistance (mean throughout the study period being 3200 kPa), while the recently abandoned lands showed slightly smaller values (the mean throughout the study period in both burned and unburned recently abandoned lands was 3100 kPa).

Data analysis indicated higher penetration resistance values in burned plots ($F=8.855$, $p=0.021$) as well as a significant interaction between Age of abandonment and Fire ($F=7.539$, $p=0.029$). This interaction indicated different responses to fire as a consequence of the age of abandonment and suggested the need to analyse separately recently abandoned lands and pine forest.

In the case of the recently abandoned lands, we did not observe any differences in penetration resistance three months after the fire (Figure 1, left). However, measurements carried out 12 months and 24 months after the fire showed higher values in burned than in unburned recently abandoned lands. From this moment on, the temporal dynamics of both burned and unburned recently abandoned lands were similar. This fact was indicated by a residual significance of the Time factor ($F=4.777$, $p=0.054$) and a lack of significance of the Fire factor ($F=0.021$, $p=0.893$).

In the case of the pine forest, topsoil penetration resistance was already higher in burned than in unburned plots three months after the fire (Figure 1, right). Furthermore, values from burned pine forest showed a remarkable increase during the first year and remained higher than results obtained in unburned pine forest until the sixth year after the fire. In the same way, data analysis showed a significant effect of the Fire factor ($F=20.281$, $p=0.011$) and a residual significance of the interaction between Time and Fire ($F=3.036$, $p=0.100$).

Short-term increases in soil surface compaction after fire have been described in other marly soils (Llovet et al., 1996; Serrasolses et al., 2004) and have been attributed to the impact of raindrops on an unprotected soil surface. On the Guadalest site, this phenomenon was observed at both burned levels (recently abandoned lands and pine forest). Moreover, the facility to return to the unburned values was in accordance with the plant response after the fire. Burned pine forest showed a slow plant response. As a consequence, a high percentage of the soil surface remained unprotected in the short and medium term after the fire (Figure 2). On the contrary, recently abandoned lands showed a short period of unprotected soil surface together with a quick return to the unburned soil surface compaction dynamics. This observed behaviour could not be explained by the structural stability of the soil surface: Pine forest showed higher structural stability than recently abandoned lands, and its stability increased as a consequence of the fire (Llovet, 2005).

In conclusion, taking into account that plant response is a key factor influencing soil surface compaction dynamics after fire, the results of this study indicate that old fields colonised by *P. halepensis* forest are more vulnerable to fire than recently abandoned fields.

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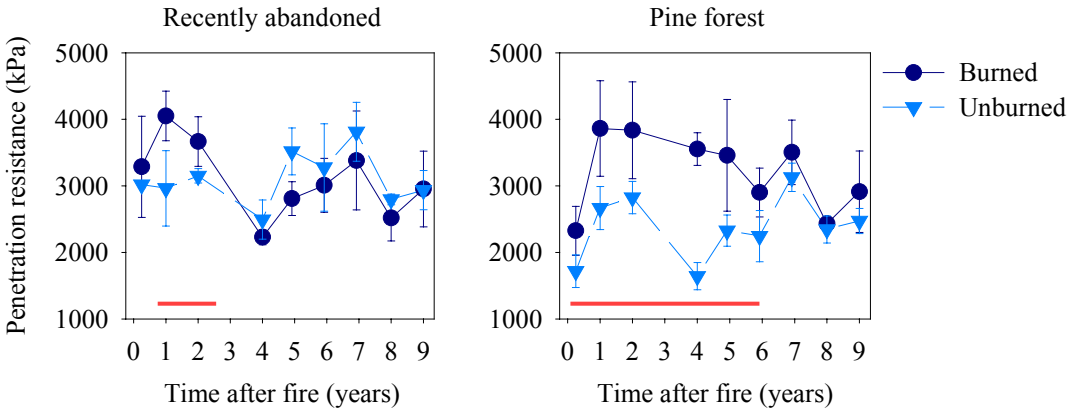

Figure 1 Temporal dynamics of soil surface compaction observed in recently abandoned fields (left) and in pine forest (right). Mean values and standard deviations. Red lines indicate the period of increased surface compaction following the forest fire.

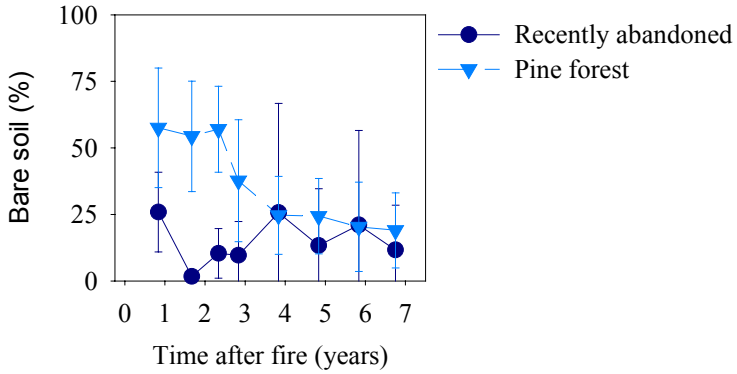

Figure 2 Percentage of bare soil after the fire on the Guadalest study site. Mean values and standard deviations

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